

Finite Element Analysis of a Novel Aircraft Seat against Static Certification Requirements (CS 25.561)

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ABSTRACT

Due to the competitive nature of the airline industry and the desire to minimise aircraft weight, there is a continual drive to develop lightweight, reliable and more comfortable seating solutions, in particular, the development of a new generation slim economy seat. The key design challenge is to maximise the “living space” for the passenger, with strict adherence / compliance to Safety Regulations.

This paper presents the analysis led design using finite element analysis of an innovative seat concept developed by BlueSKy Designers Limited, which has been acclaimed as “The most exciting development in aviation in over 30 years” and has won the company numerous awards. A generous angle of recline (40 degrees), movement of the “Seat Pan” along different gradients, and unique single “Forward Beam” design, distinguishes “Sleep Seat” from current generation seats.

Compliance against Static Strength requirements (CS25.561) through a sequential model development approach was performed, in order to predict the stress induced in the primary seat structure, against static certification requirements. A critical design parameter is ensuring seat interface loads are below airline limits, which resulted in the inclusion of seat stud and track details in the finite element model.

This stepwise and validated analysis framework, which includes mesh sensitivity studies, modelling of bolt-preload, representing bolted joints in FEA and obtaining a converged solution for non-linear FEA was essential in order to allow different concepts to be assessed virtually, thereby reducing development cycle time. The findings from this paper demonstrate that the seat is safe against CS 25.561.

1 INTRODUCTION

This research provides an assessment of an innovative design called “Sleep Seat” [1], which consists of a forward beam, seat leg, Boomerang, and Seat pan as shown in Figure 1. This innovative design includes movement of the seat pan along the gradient maximising the space for leg spread, 40 degree generous recline of the backrest within a fixed outer shell, single Forward (FWD) beam design eradicating the undercarriage below the seat pan, significant reduction in the part count, and an ultra lightweight design saving more than 3kg of mass over existing products [1], [2].

The objective of the research is to develop a practical modelling methodology that can be used to assist designers in assessing the suitability of a chosen seat configuration, through a sound understanding / application of the FE Method, together with demonstrating a critical assessment of the quality of the numerical results through appropriate verification methods.

2 CERTIFICATION SPECIFICATIONS (CS) USED AS SAFETY GUIDELINES

CS has been followed as a guideline for safety in this research as it encompasses works of all relevant governing bodies in international commercial aviation and agrees to some extent with its US equivalent FAR (Federal Aviation Regulations) [3]. CS sections 25.561 and 25.562 give static and dynamic loads during emergency landing conditions respectively [4]. As a first step, this paper focuses on static 9g compliance in the forward direction, as defined in CS 25.561.

As this project was in the conceptual phase, Finite Element Analysis (FEA) was used to compare different designs. Going further, this can be considered as a baby step towards “Certification By Analysis (CBA)” a programme undertaken by “Federal Aviation Administration (FAA) [5]. To reduce the number of variables at initial stage, focus was on successful design of Forward (FWD) beam and leg which are critical components of “Primary Load Path (PLP)” subjected to “Forward 9g”.

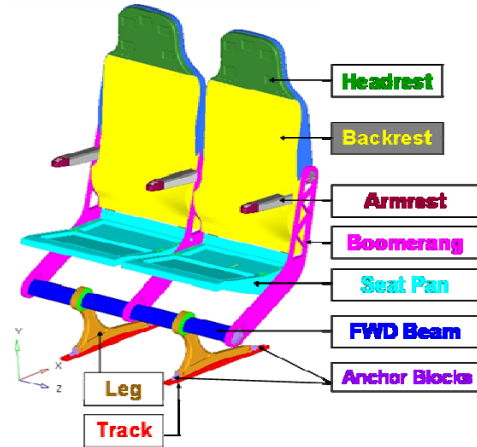


Figure 1 Nomenclature of “Sleep Seat” (Courtesy BlueSky) [1]

3. SPREADSHEET FOR INITIAL SIZING OF FORWARD BEAM

Analytical model for the “FWD beam” was developed (Spreadsheet), which could estimate the bending stress induced in it for “Forward 9g” loads, with design variables such as its cross-section and thickness. C3D8I (linear brick element with incompatible modes) used in Abaqus/Standard) gave satisfactory results, when two brick elements through thickness with aspect ratio of 1:1 in critical areas and 3:1 in non-critical areas gave reliable results with optimum solution time and storage requirements. Good agreement between spreadsheet and FEA verified the FE model and demonstrated the usefulness of the spreadsheet as a quick and simple conceptual design tool for initial sizing of the FWD beam.

4 SEQUENTIAL FE MODEL DEVELOPMENT FOR THE PRIMARY LOAD PATH

A stepwise procedure for the development of the leg required an evolution in detailed FE model, where each model contains the refinements suggested by results supplied by previous models, resulting in the final model containing all necessary details, optimum mesh and boundary conditions (Figure 2) [6].

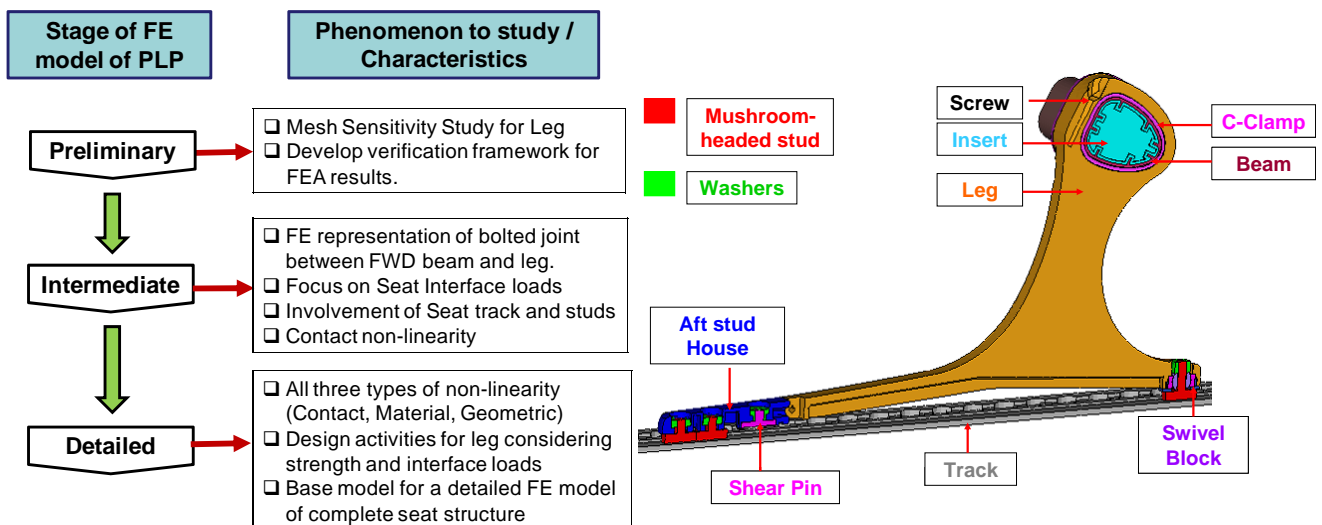


Figure 2 Sequential Development Approach for FE model of the “Primary Load Path (PLP)” (left) and cross sectional view of the detailed FE model generated for FWD beam / leg (right)

The mesh studies for the leg showed that geometrically versatile tetrahedral elements were a very attractive option compared to brick elements, as they provided an 85% reduction in the FE model building time and 40% in the solution time, whilst still providing reasonably accurate results. Care should be taken to ensure two elements through thickness are used.

During this stepwise development, a procedure to verify computational accuracy of FEA results was drafted. It included checks as reaction force equilibrium, stress difference between “with nodal averaging” and “without nodal averaging” and displacement continuity. It was found that, results satisfy all the checks. For non-linear FEA, checks such as residual force and moment, ratio of artificial damping energy to strain energy, distribution of contact pressure and forces transmitted across interfaces were added to above checks.

4.1 FE REPRESENTATION OF BOLTED JOINT IN SEAT

FWD beam is attached to the leg with the help of two M5 bolts. Three different ways to represent this bolted joint in FEA were studied: coincident nodes at FWD beam and leg interface (Case I- preliminary model), tied contact (Case II) and actual modelling of studs and corresponding contacts (Case III). Flexibility (to absorb initial penetrations), less pre-processing time required (80% lesser than that in Case III) and acceptable results; favoured the used of “Tied contact” definition at “FWD beam and leg” interface.

During study of bolted joint between “FWD beam and leg”, a stepwise procedure for FE modelling of “Bolt-preload” and its integration with inertia loads (CS 25.561); was developed and implemented.

4.2 METHODOLOGY TO EXTRACT “SEAT INTERFACE LOADS (SIL)”

Leg designing depends on its strength as well as on SIL i.e. static loads applied by the seat to the floor [7]. The challenge was to develop an FE model, which could give enable designers to perform sensitivity studies to assess the changes in the resulting stress due to different stud configurations for the applied “Forward 9g” loads. Going further, classification of contact pairs in suitable groups for evaluating SIL was accomplished through pilot studies, and a systematic approach for extracting SIL using FEA was developed. With this study, an “Intermediate” FE model of PLP was completed.

4.3 TECHNIQUES TO HANDLE “RIGID BODY MOTION”

For static non-linear contact FEA of “Sleep Seat”, two prominent reasons for non-convergence were initial penetrations and clearances. Model with initial penetrations, suffers from very high stress levels during as penetration is considered as interference fit by the solver, even though unintentional [8]. In case of initial clearances, FEA algorithms undergo unrestrained motion and frictional sticking is not effective [8]. Use of same element faces in mating area, clever use of “Mesh algorithm” e.g. use “Union Jack R-tri” instead of “Standard R-tri” element and a nominal “Bolt Pre-load” of 1KN – 2KN to close initial gaps were some of the techniques, which were successfully used to deal with “Rigid Body Motion”.

5 DESIGN PHASE AND NON-LINEAR FEA OF COMPLETE SEAT

An elliptical cross-section with two millimetres thickness was chosen for FWD beam using spreadsheet. Inserts were added at high stress locations for local reinforcements. “I” section was chosen for leg considering the second moment of area, while length of the leg was decided by carefully studying SIL induced.

A non-linear FE model of complete seat structure with total 62 contact pairs with penalty algorithm, 11 tied contacts, 32 MPC connections (rigid) and 2 MPC connectors with “End Release”, involving material and geometric non-linearity was developed, which could give outputs such as stress and interface loads when subjected to loads as specified in CS 25.561. Total number of nodes and elements are 354862 and 285679 respectively. Total mass of this seat structure is around 7 kg.

The total weight considered for the load application was 87.48kg, which included an occupant mass of 77

kg and additional mass to represent in-plane entertainment items. Bottom surfaces of track were constrained for all dofs during the simulation and loads were applied at the point, as specified in National Aerospace Standard (NAS 809) [9]. It was found that the components of PLP (FWD beam and leg) are “Safe” against the critical loads as specified in CS 25.561.

6. SUMMARY

The development of a practical methodology was successfully used during the conceptual design phase, which led to significant structural design modifications, which now allows the company to build and test a prototype with more confidence. Methodology includes:

- FE modelling strategy for individual components through Mesh Sensitivity Study,
- Framework to critically assess the FEA results,
- Solutions to deal with “Rigid Body Motion” and “Initial Penetration”.
- Modelling of “Bolt Pre-load” using Abaqus / Standard,
- Simplified yet reasonable FE representation of bolted joint in seat structure,
- Extraction of “Seat Interface loads”,
- To obtain the converged solution for the complete seat subject to static loads (CS 25.561) including all types of non-linearities i.e. contact, material and geometry; using Abaqus / Standard.

7 FUTURE SCOPE

The next phase of this work is to perform experimental tests to support model validation. Once static compliance has been demonstrated, this project will then consider the dynamic certification requirements through the incorporation of an anthropometric hybrid III numerical dummy. Based upon the findings, the numerical tools will be used to optimise the seat structure for minimum weight.

8. REFERENCES

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